Probing the Innermost Regions of AGN jets and their Magnetic Fields with RadioAstron

José L. Gómez (IAA-CSIC),
A. Lobanov (MPIfR), G. Bruni (MPIfR),
Y. Kovalev (ASC), et al.
on behalf of the Polarization RadioAstron KSP team

Polarized Emission from Astrophysical Jets. Ierapetra, June 12-16 2017

A KSP for polarimetric Space-VLBI with RadioAstron

Early Science			
Target	**Date**	**Band**	**Status**
0642+499	9 March 2013	L	Lobanov et al. (2015)

AO-1, AO-2, and AO-3 Observations				
Target	**Date**	**Band**	**Correlation**	**Status**
BL Lac	29 Sep. 2013	L	Yes	Imaging
BL Lac	11 Nov. 2013	K	Yes	Gómez et al. (2016)
3C273	18 Jan. 2014	K	Yes	Bruni et al. (in press)
3C273	13 June 2014	L	Yes	
3C279	10 March 2014	K	Yes	
OJ287	04 April 2014	K	Yes	Gómez et al. (in prep)
0716+714	3 January 2015	K	Yes	
3C345	30 March 2016	L	No	
OJ287	16 April 2016	L	No	
OJ287	25 April 2016	K	No	
3C345	4 May 2016	K	No	

Performed AO-4 Observations			
Target	**Date**	**Band**	**Complementary**
3C454.3	8 October 2016	K	GMVA 3 mm October 2016
CTA102	17 October 2016	K	GMVA 3 mm October 2016
OJ287	7 March 2017	K	GMVA+ALMA, EHT+ALMA 2017

A KSP for polarimetric Space-VLBI with RadioAstron

Performed AO-4 Observations			
Target	**Date**	**Band**	**Complementary**
3C454.3	8 October 2016	K	GMVA 3 mm October 2016
CTA102	17 October 2016	K	GMVA 3 mm October 2016
OJ287	7 March 2017	K	GMVA+ALMA, EHT+ALMA 2017

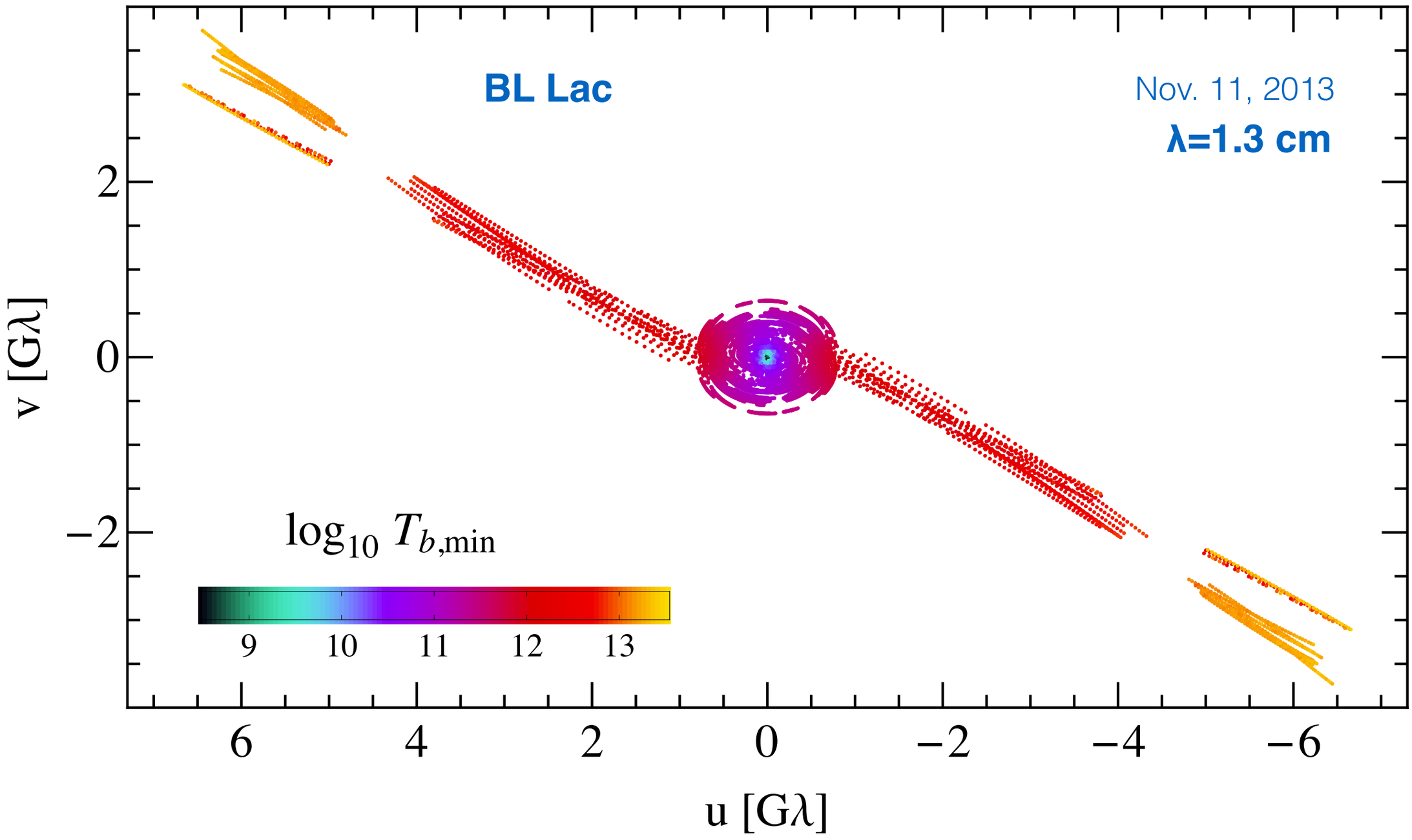
RA Approved AO-5 (2017-2018) Observations			
Target	**Date**	**Band**	**Complementary**
BL Lac	September 2017	K	GMVA 3 mm October 2017
3C120	January 2018	K	GMVA 3 mm October 2017
3C279	Jan-Feb 2018	K	GMVA+ALMA, EHT+ALMA 2018
3C273	Feb-May 2018	K	GMVA+ALMA, EHT+ALMA 2018
OJ287	22-27 April 2018	K	GMVA+ALMA, EHT+ALMA 2018
M87	March 2018	K,L	Nearby AGN KSP,GMVA,EHT 2018

Unique opportunity for first time *polarimetric* VLBI-imaging at the highest angular resolution (*20-40 μas*) combining 3 wavelengths (1.3 mm, 3 mm, and 1.3 cm) with *almost matching beam and quasi-simultaneously* in an AGN.

Observations of BLLac at K-band

RadioAstron observations of **BL Lac at 1.3 cm** were performed in November 11, 2013.

BL Lac was observed together with 15 ground antennas: EF, MH, ON, SV, ZC, MC, BD, BR, HN, KP, LA, NL, OV, PT, MK.



Gómez et al. (2016)

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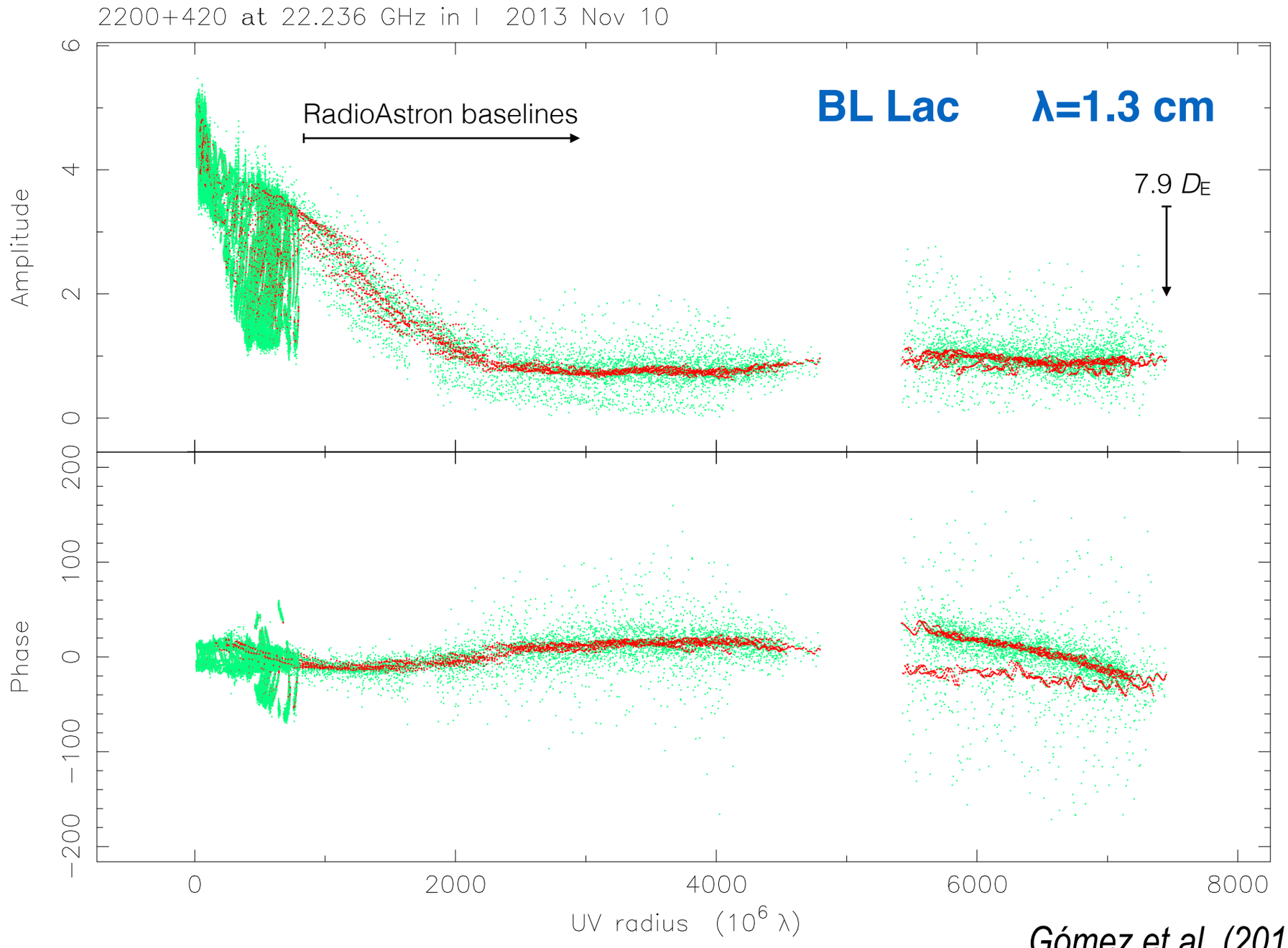
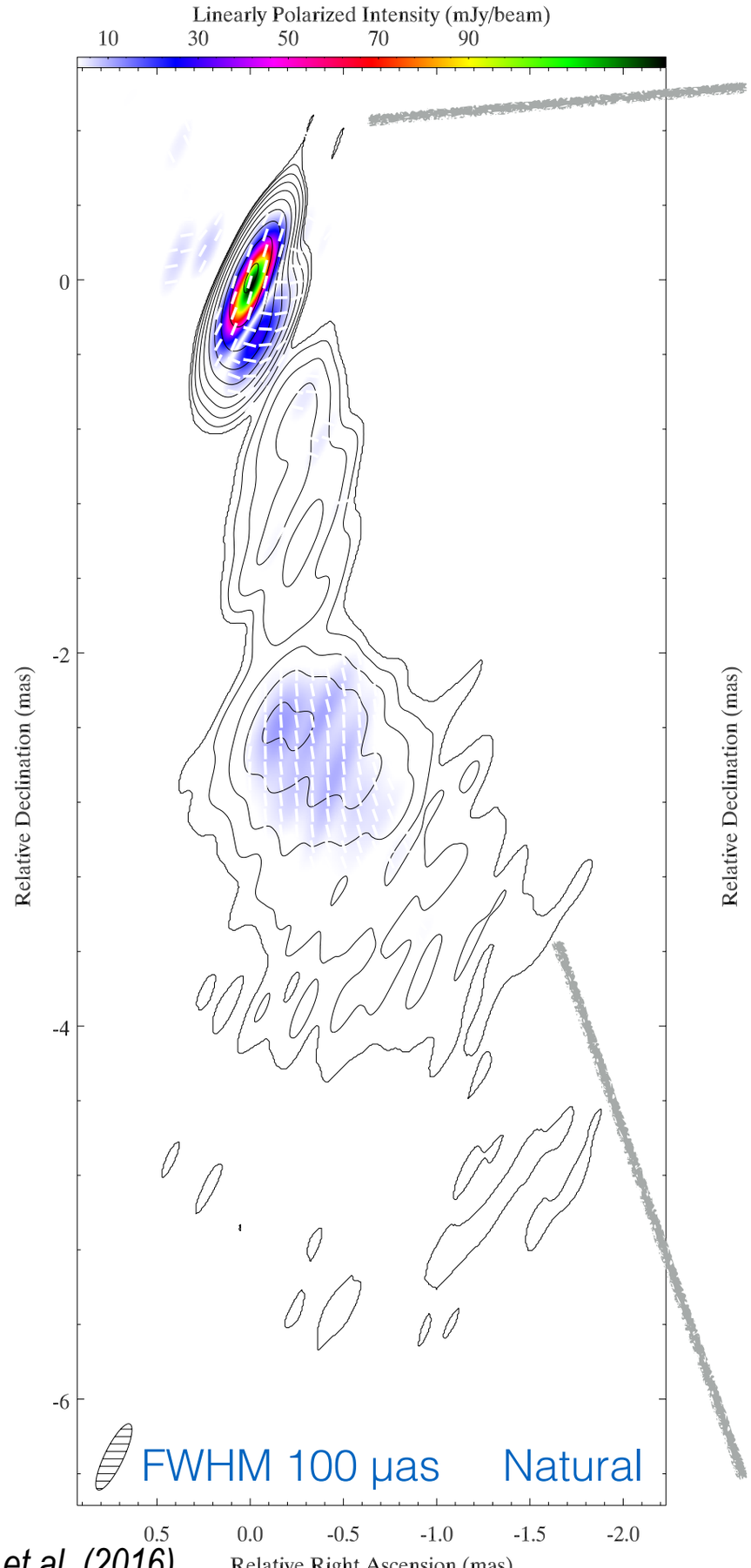
BL Lac was observed together with 15 ground antennas: EF, MH, ON, SV, ZC, MC, BD, BR, HN, KP, LA, NL, OV, PT, MK.

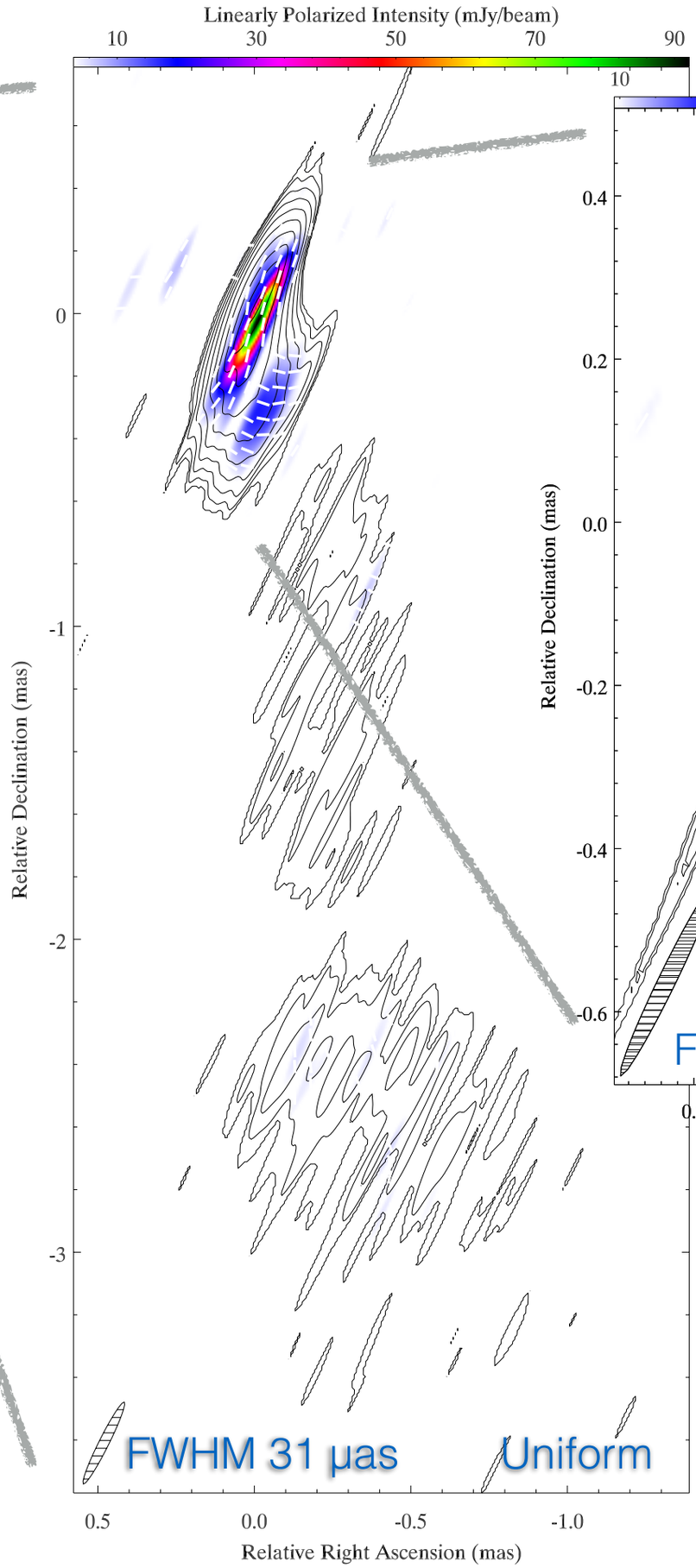
Ground-space fringes up to projected baseline distance of **7.9 Earth's diameters** in projection.

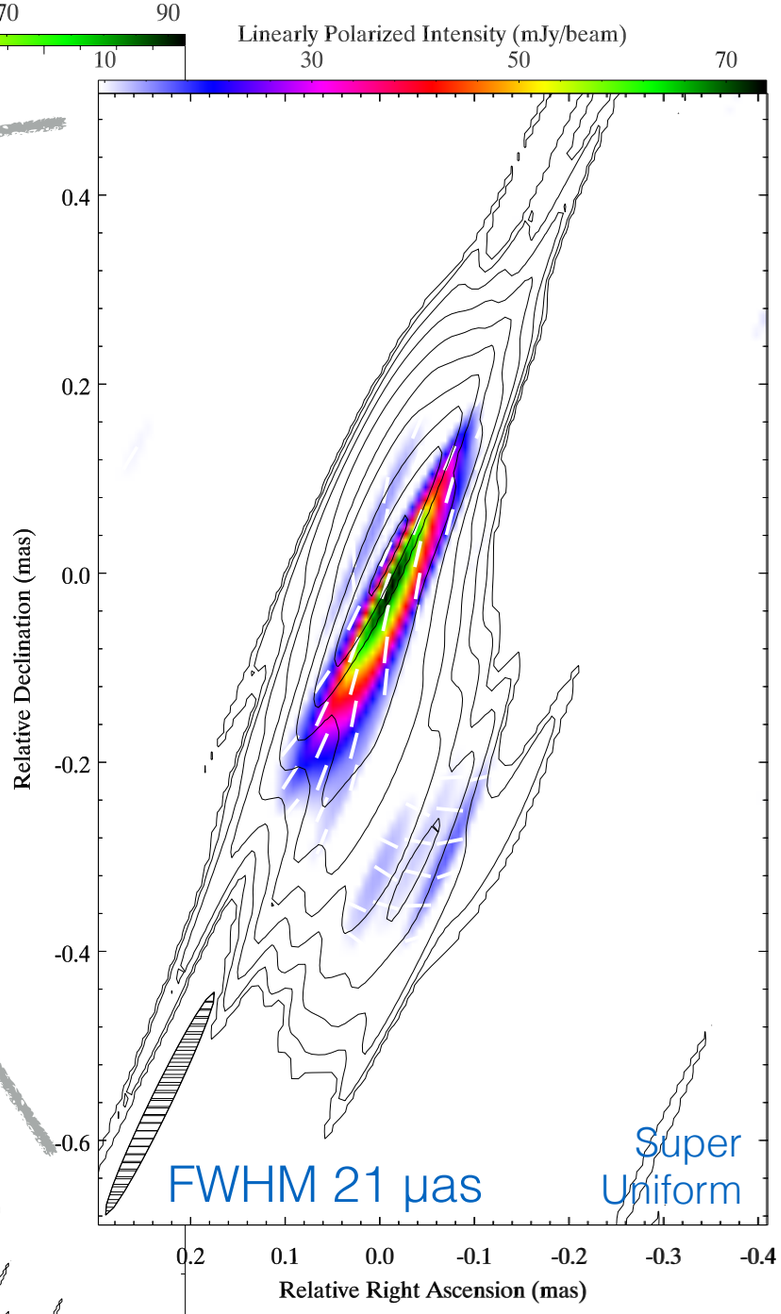


Gómez et al. (2016)

Observations of BLLac at K-band

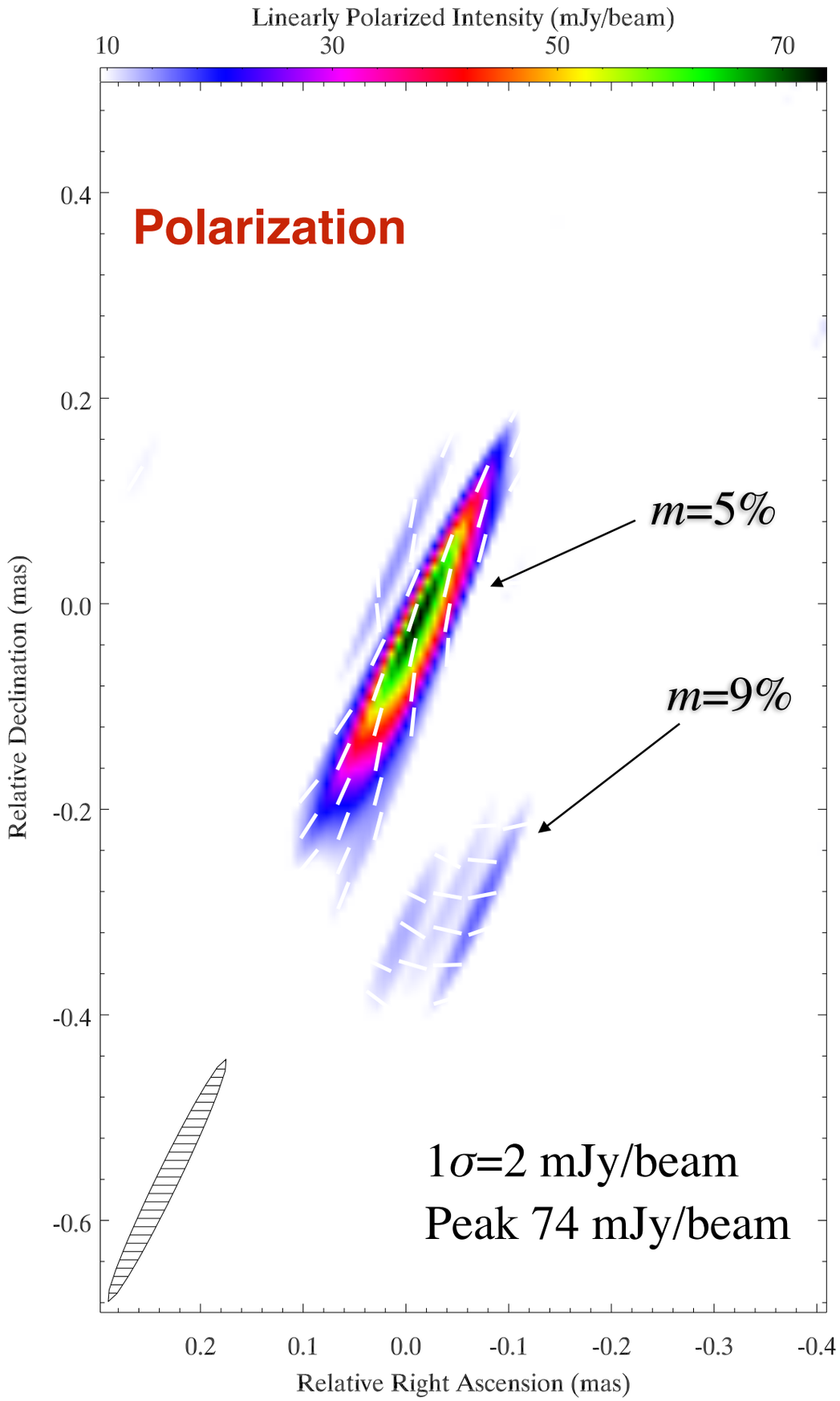


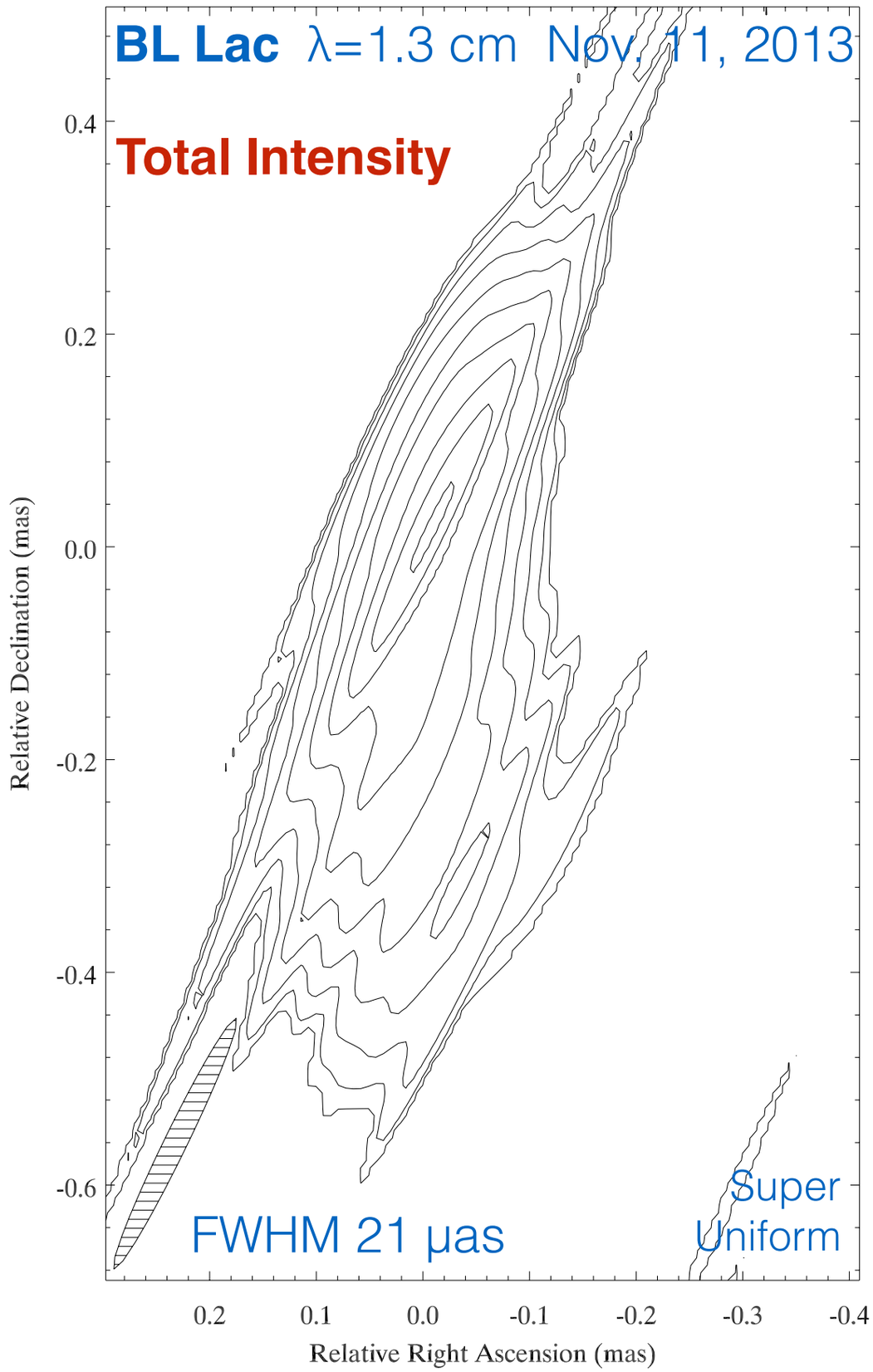




Gómez et al. (2016)

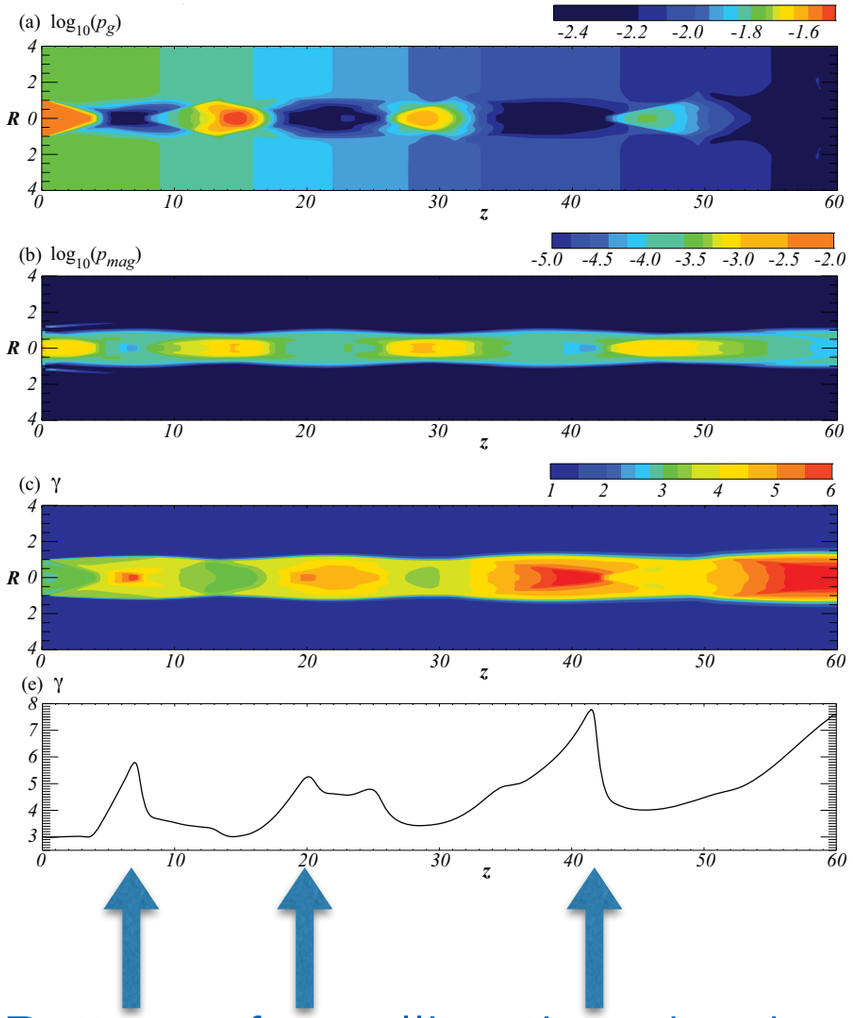
Observations of BLLac at K-band





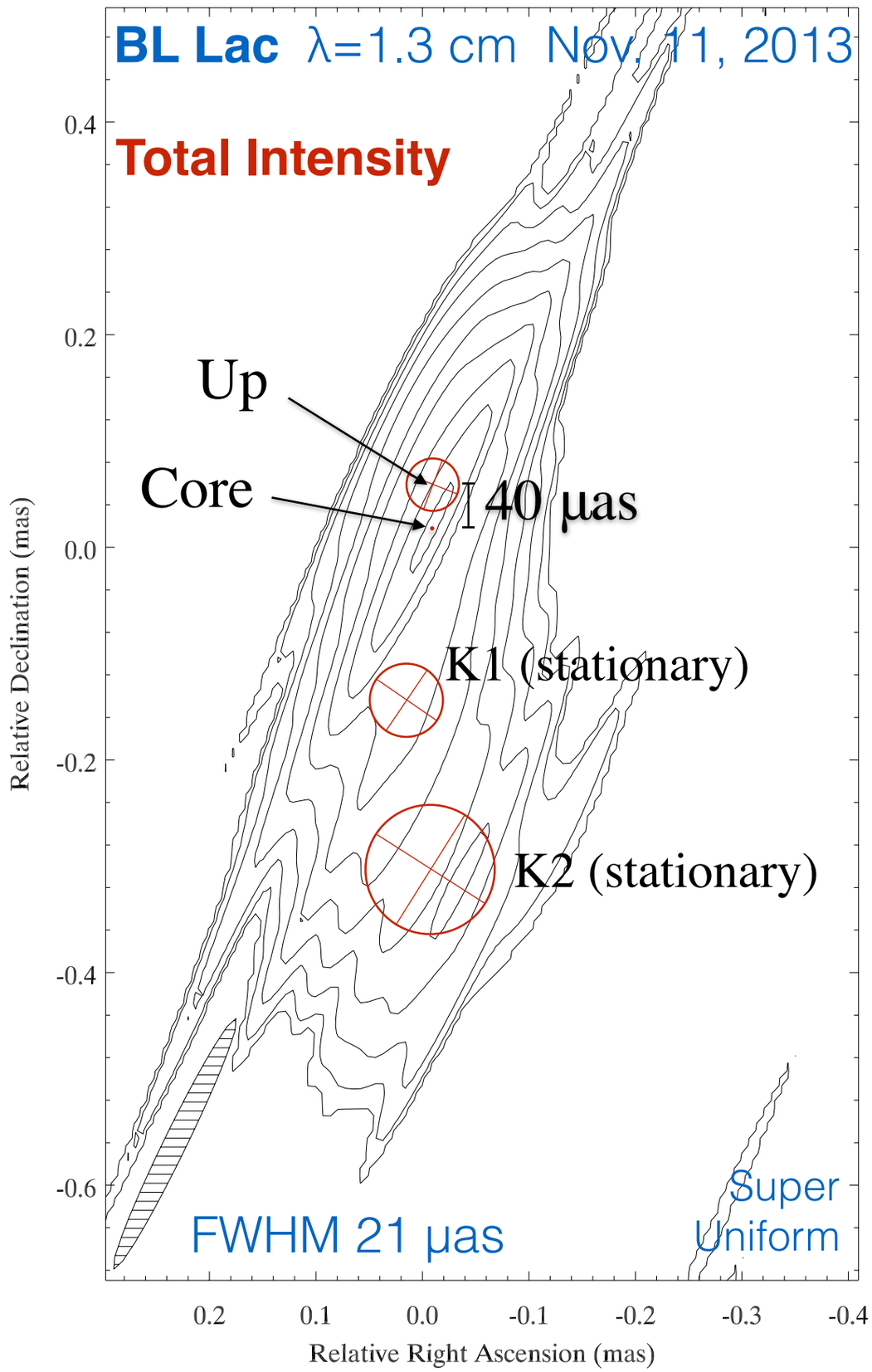
Observations of BLLac at K-band

This opens the possibility that **the core is a recollimation shock at ~40 μas for the jet apex**, in a pattern that includes also components K1 and K2 at ~100 μas and ~250 μas, respectively.



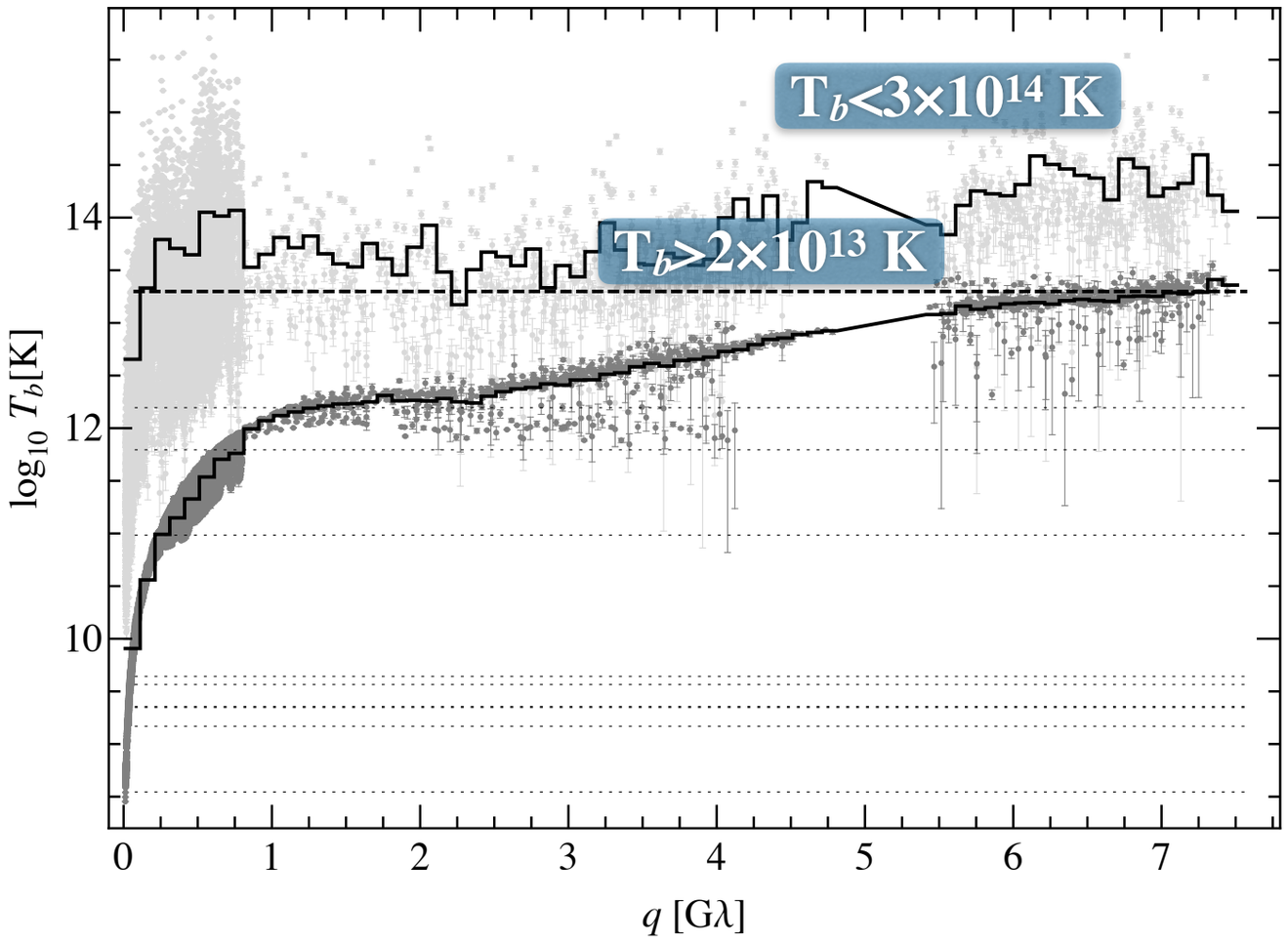
RMHD simulations reproduce the relative distance between components Core, K1, and K2 as recollimation shocks.

Gómez et al. (2016)



Observations of BLLac at K-band

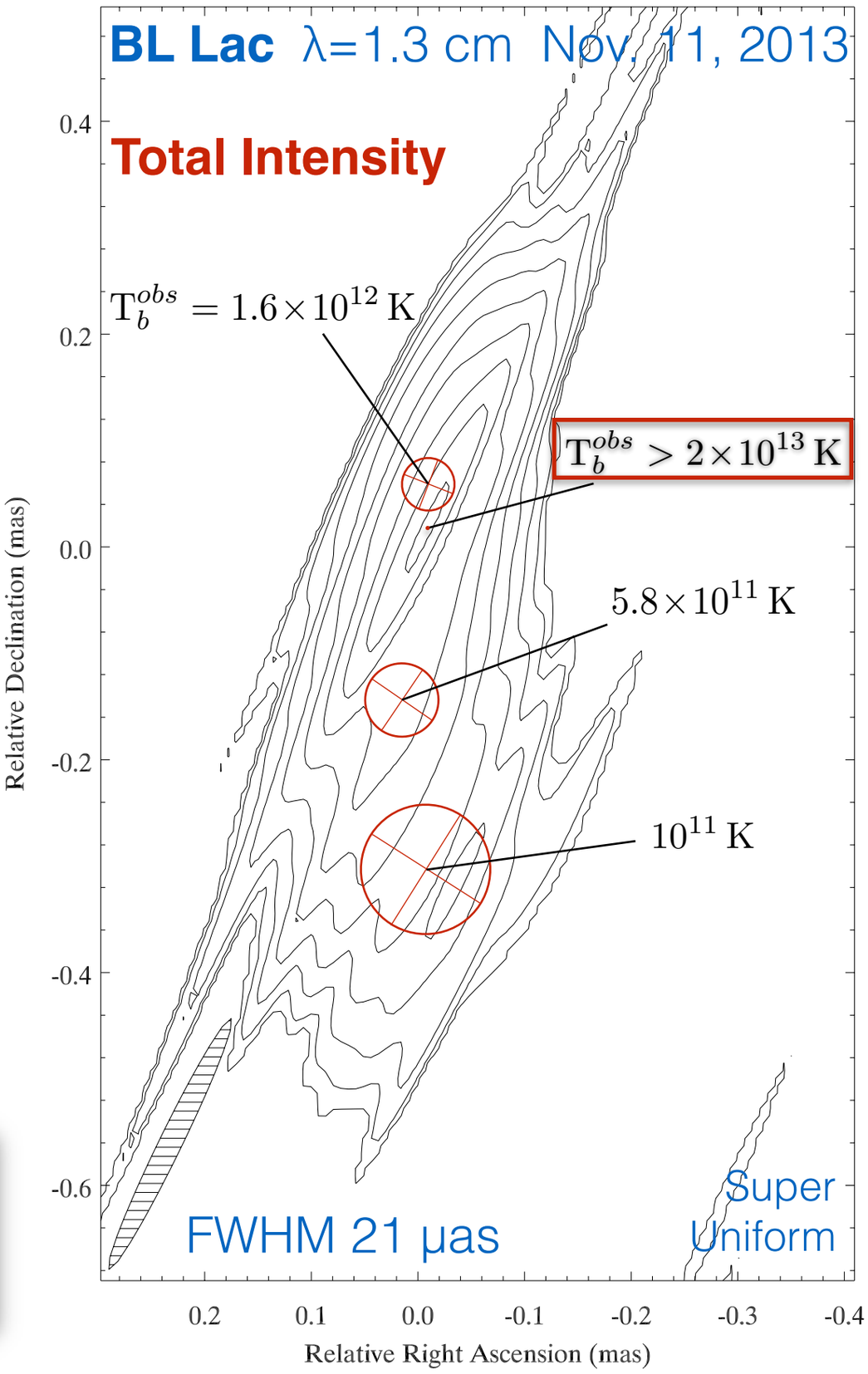
Unresolved core component has an *observed* brightness temperature of $T_b>2\times10^{13}$ K.



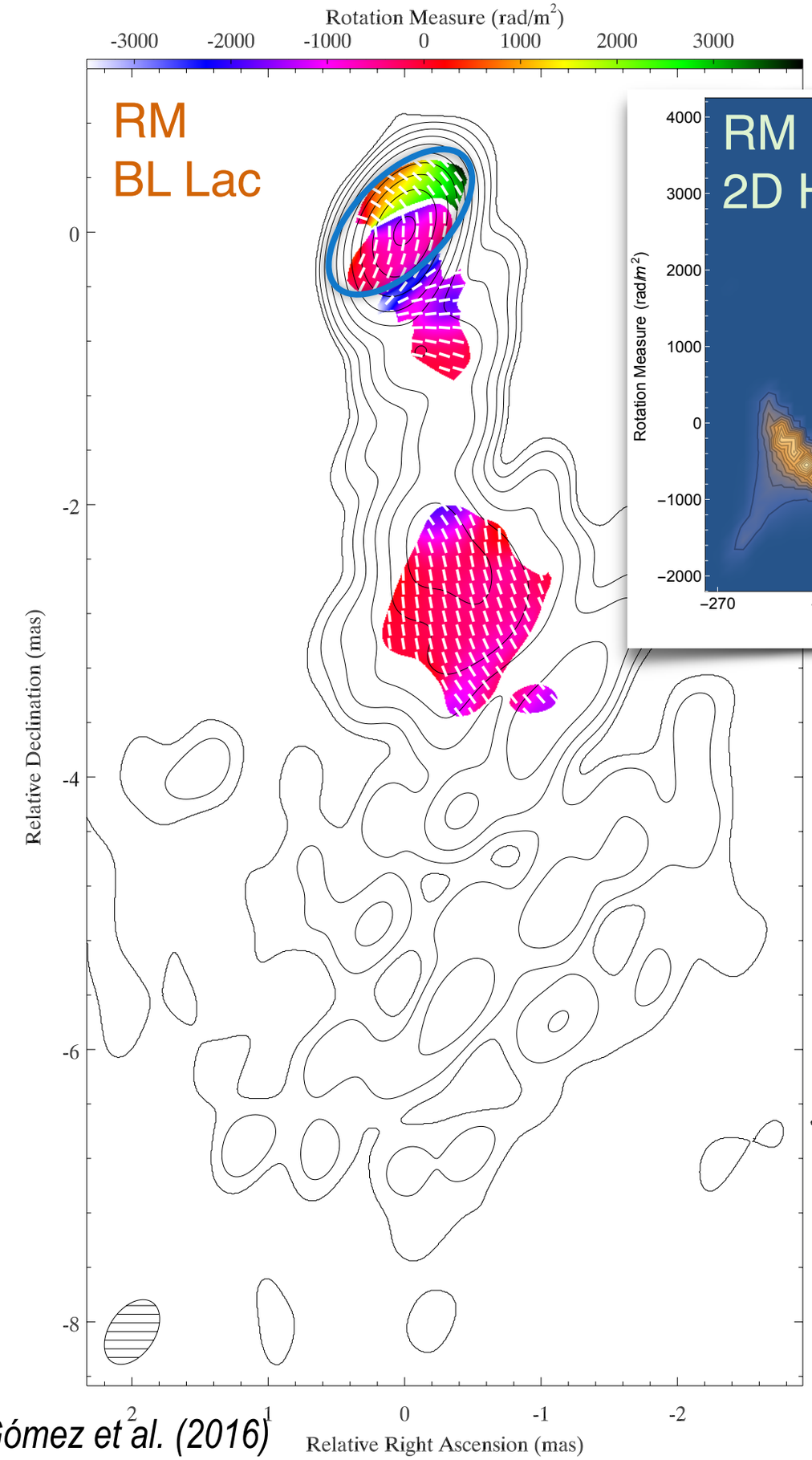
This is further supported by estimations from the visibilities amplitudes and their errors (Lobanov 2015).

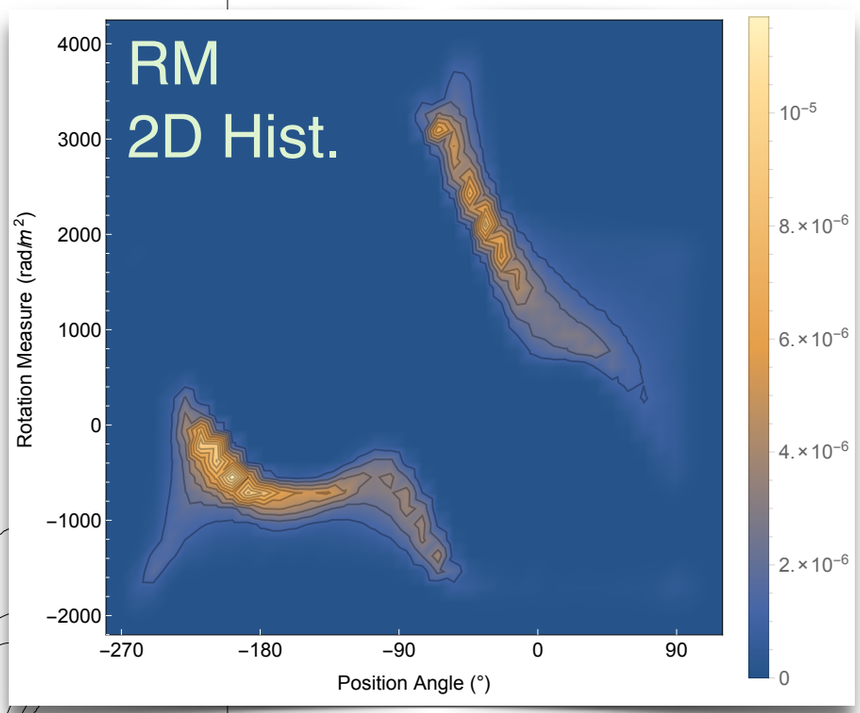
From estimated δ=7.2 we obtain an **intrinsic brightness temperature $T_{b,int}>3\times10^{12}$ K, well above the inverse Compton limit.**

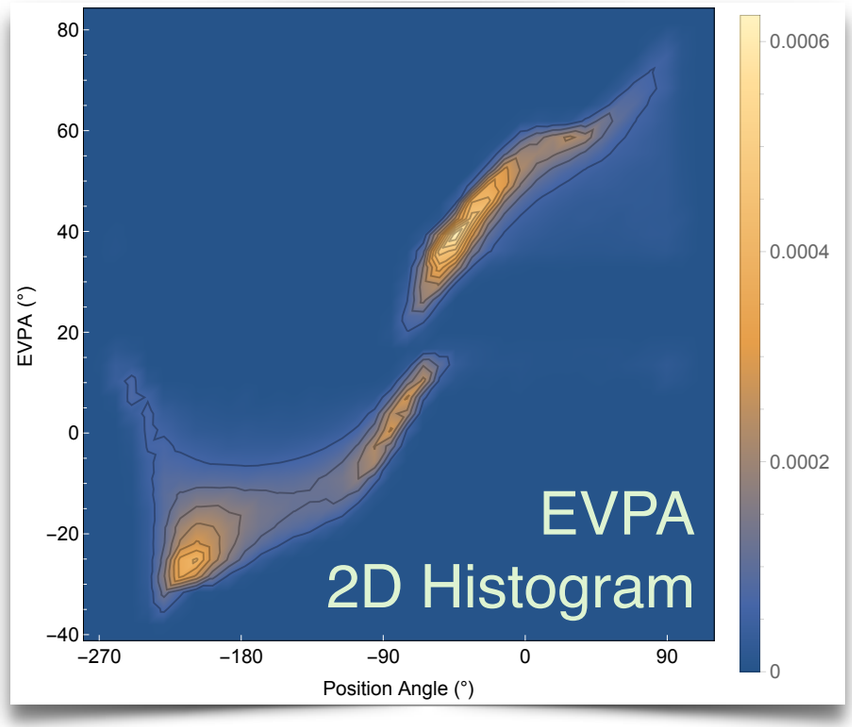
Gómez et al. (2016)



Observations of BLLac at K-band

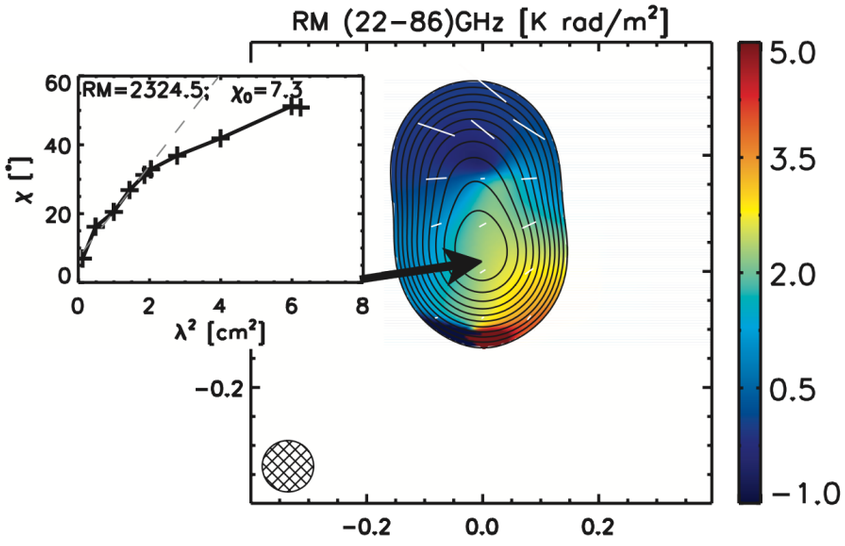






The core area shows a point symmetric structure in RM and EVPA, as shown in the 2D histograms as a function of position angle wrt the core in the selected area.

The polarization structure is consistent with the existence of a helical magnetic field threading the jet.



In agreement with RMHD simulations of jets with a helical magnetic field by Porth et al. (2011).

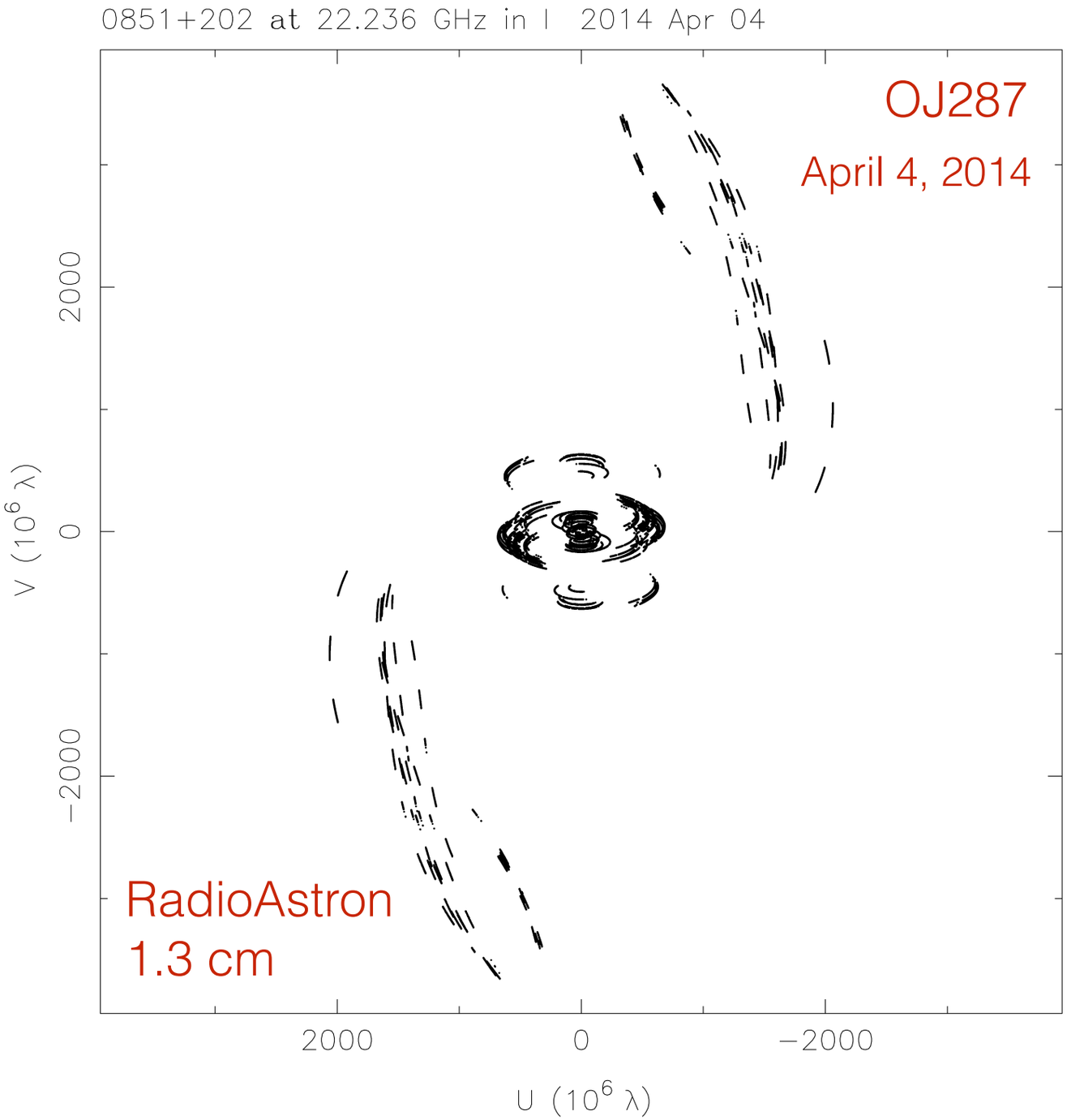
Gómez et al. (2016)

Observations of OJ287 at K-band

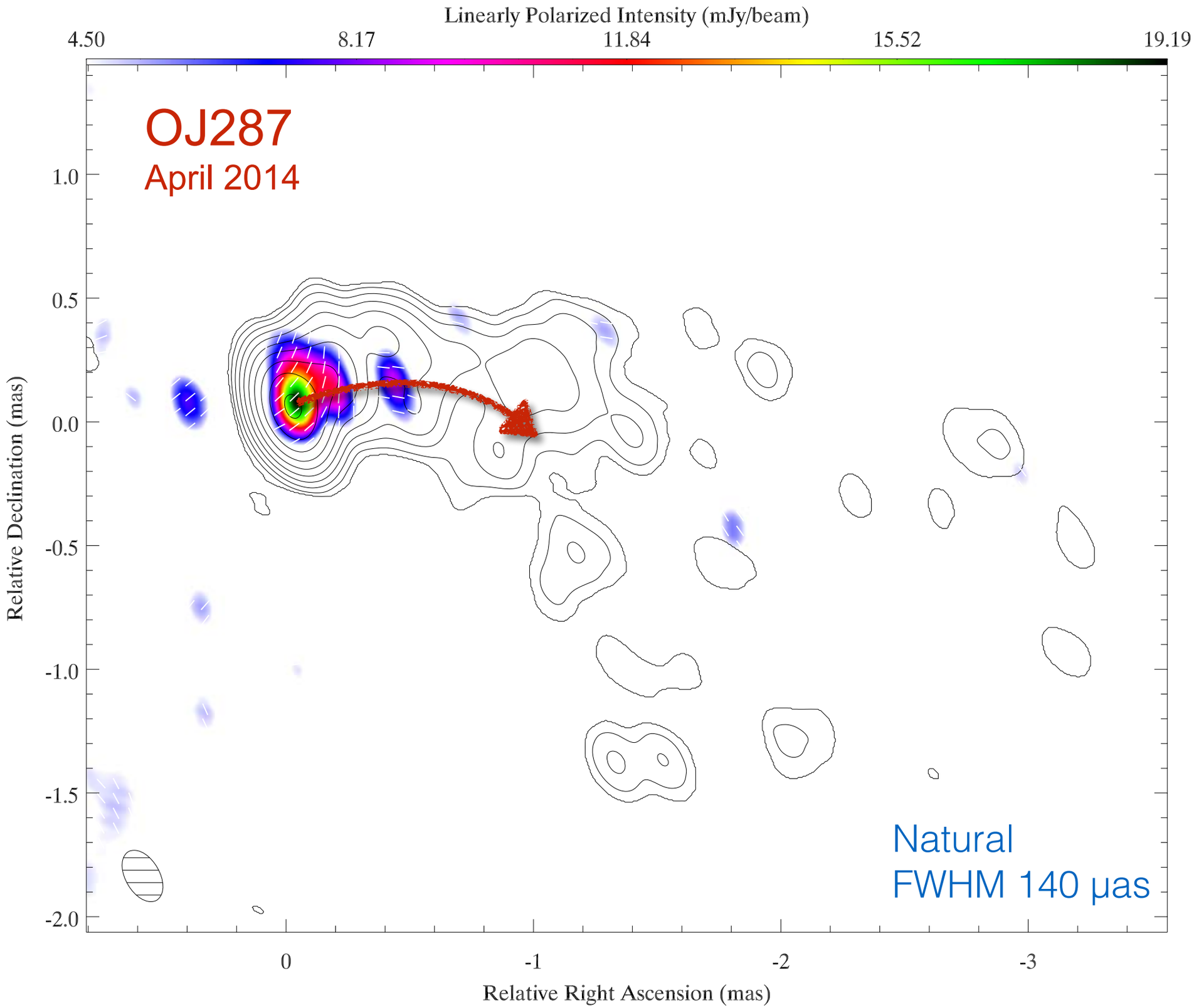
RadioAstron observations of **OJ287 at 1.3 cm** were performed in April 4, 2014.

OJ287 was observed together with 12 ground antennas including the EVN, KVN, and GBT.

Ground-space fringes (SNR~50) have been detected throughout the whole experiment, reaching **~4 Earth diameters** in projected length.

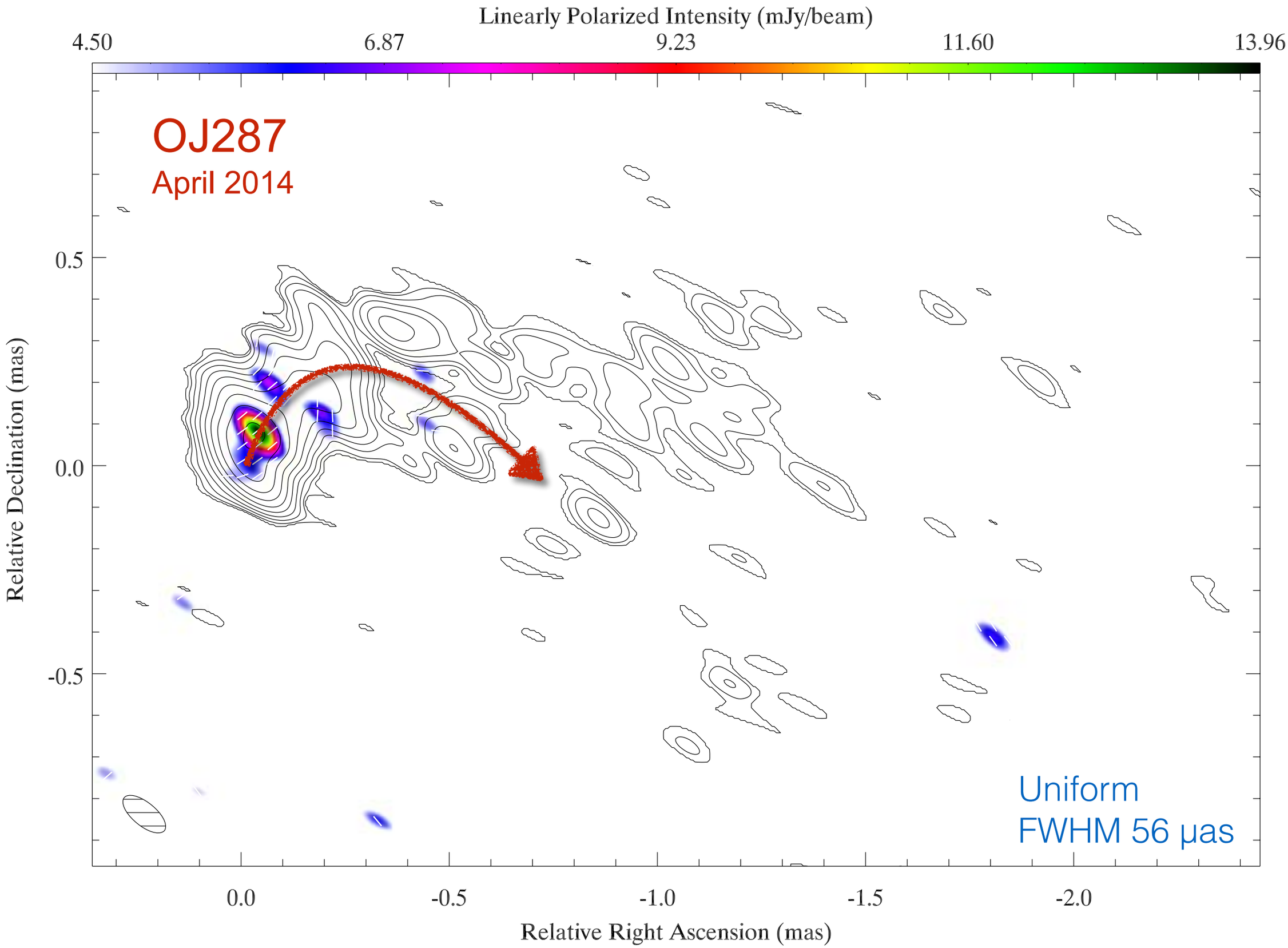


Observations of OJ287 at K-band



Peak Total Intensity 1.2726 Jy/beam (min. at 2.00 mJy/beam - Pol. 23.5% peak)
Total Intensity Contours 0.16,0.32,0.64,1.31,2.64,5.35,10.84,21.95,44.44,90% of peak
Beam FWHM 0.227x0.137 mas at 30.315 deg.

Observations of OJ287 at K-band



Peak Total Intensity 0.6220 Jy/beam (min. at 2.00 mJy/beam - Pol. 32.2% peak)
Total Intensity Contours 0.32,0.60,1.12,2.10,3.93,7.36,13.76,25.73,48.12,90% of peak
Beam FWHM 0.125x0.056 mas at 50.638 deg.

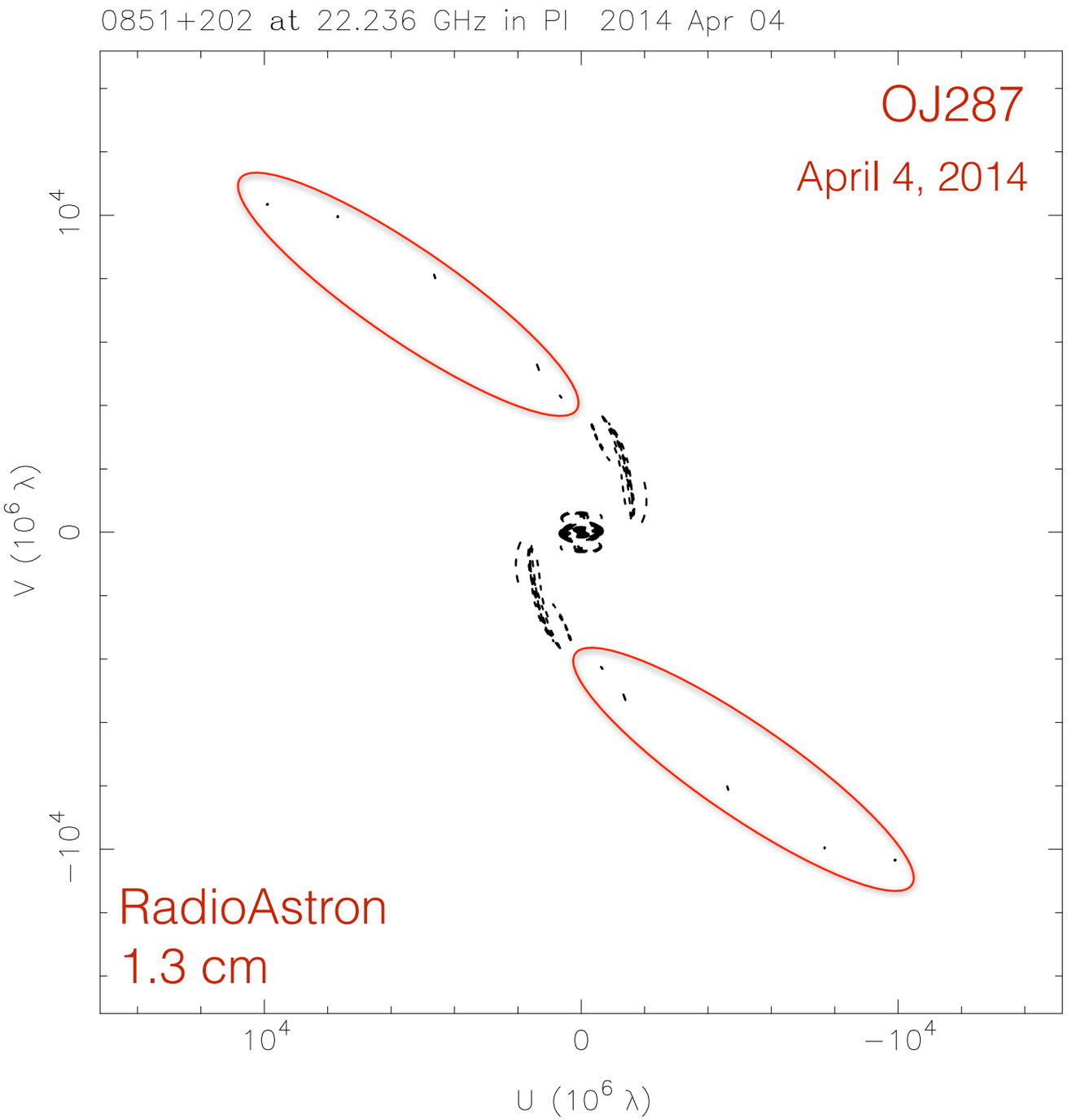
Observations of OJ287 at K-band

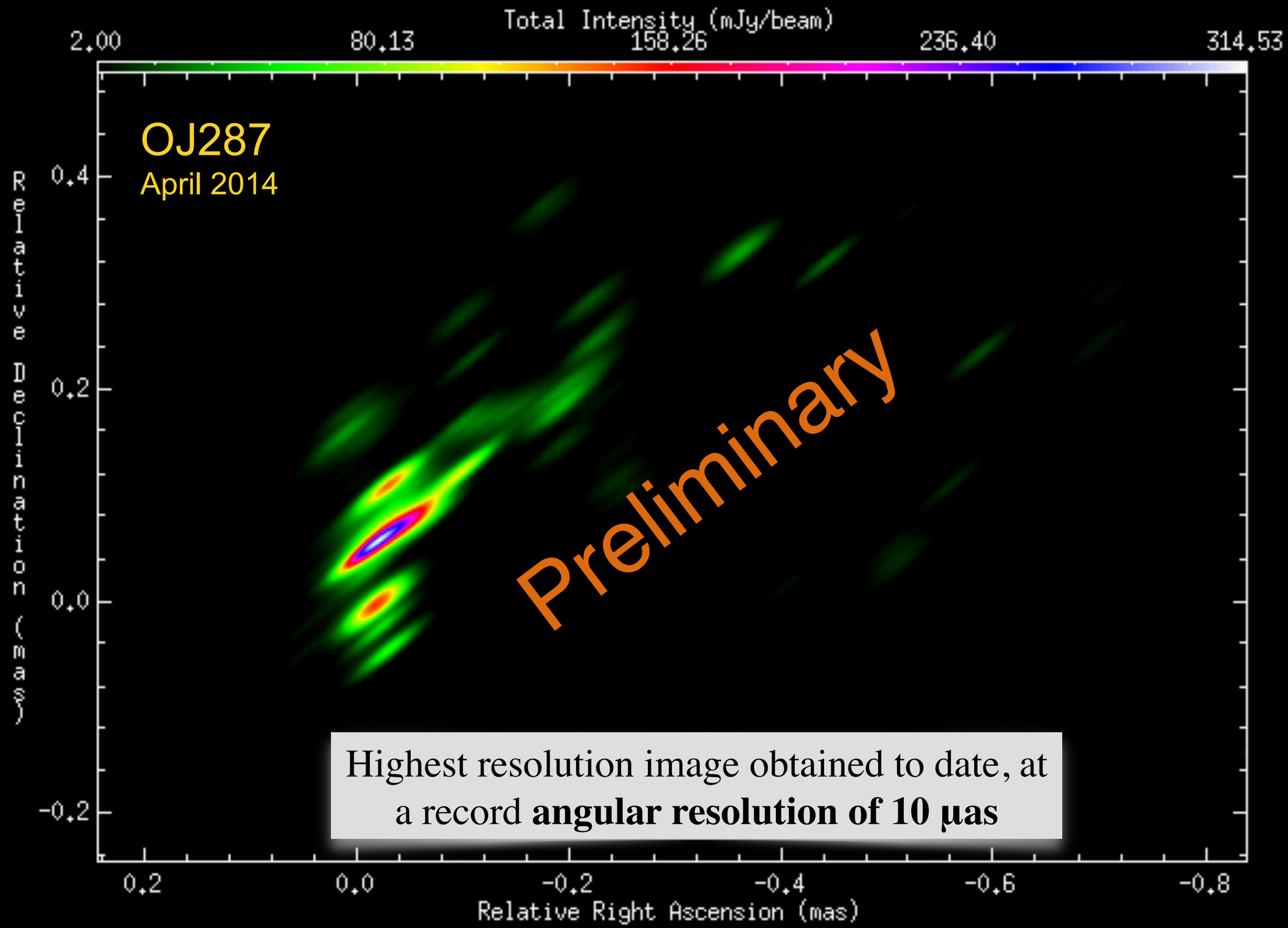
RadioAstron observations of **OJ287 at 1.3 cm** were performed in April 4, 2014.

OJ287 was observed together with 12 ground antennas including the EVN, KVN, and GBT.

Ground-space fringes (SNR~50) have been detected throughout the whole experiment, reaching **~4 Earth diameters** in projected length.

Ground-space fringes detected at a record spacing of **15.2 Earth diameters** (April 18th, SNR~11.5) by the RadioAstron Survey (PI Kovalev).



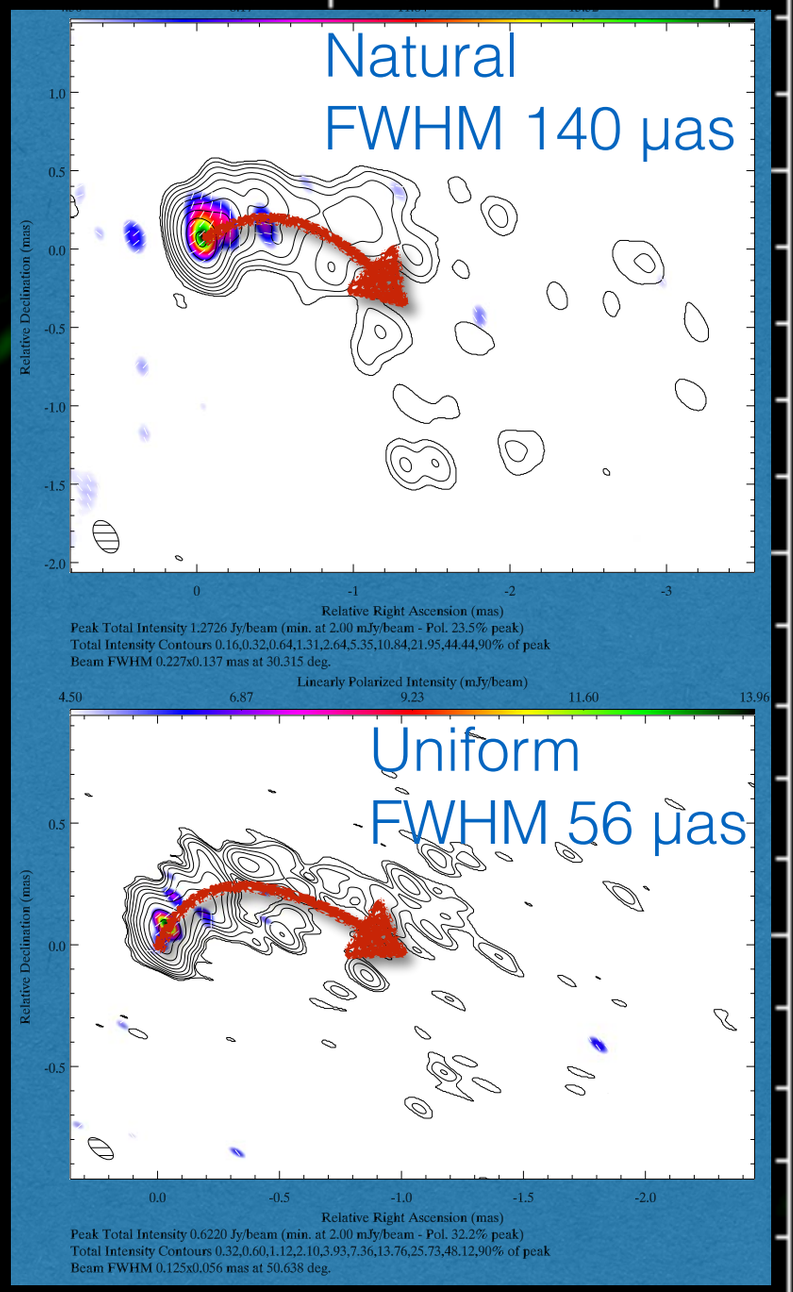

Total Intensity (mJy/beam)
2.00
80.13
158.26
236.40
314.53
OJ287
April 2014
Preliminary
Highest resolution image obtained to date, at a record angular resolution of 10 µas
Relative Declination (mas)
0.4
0.2
0.0
-0.2
0.2
0.0
-0.2
-0.4
-0.6
-0.8
Relative Right Ascension (mas)

Total Intensity (mJy/beam)
2.00 80.13 158.26 236.40 314.53

OJ287
April 2014

FWHM 10 μas

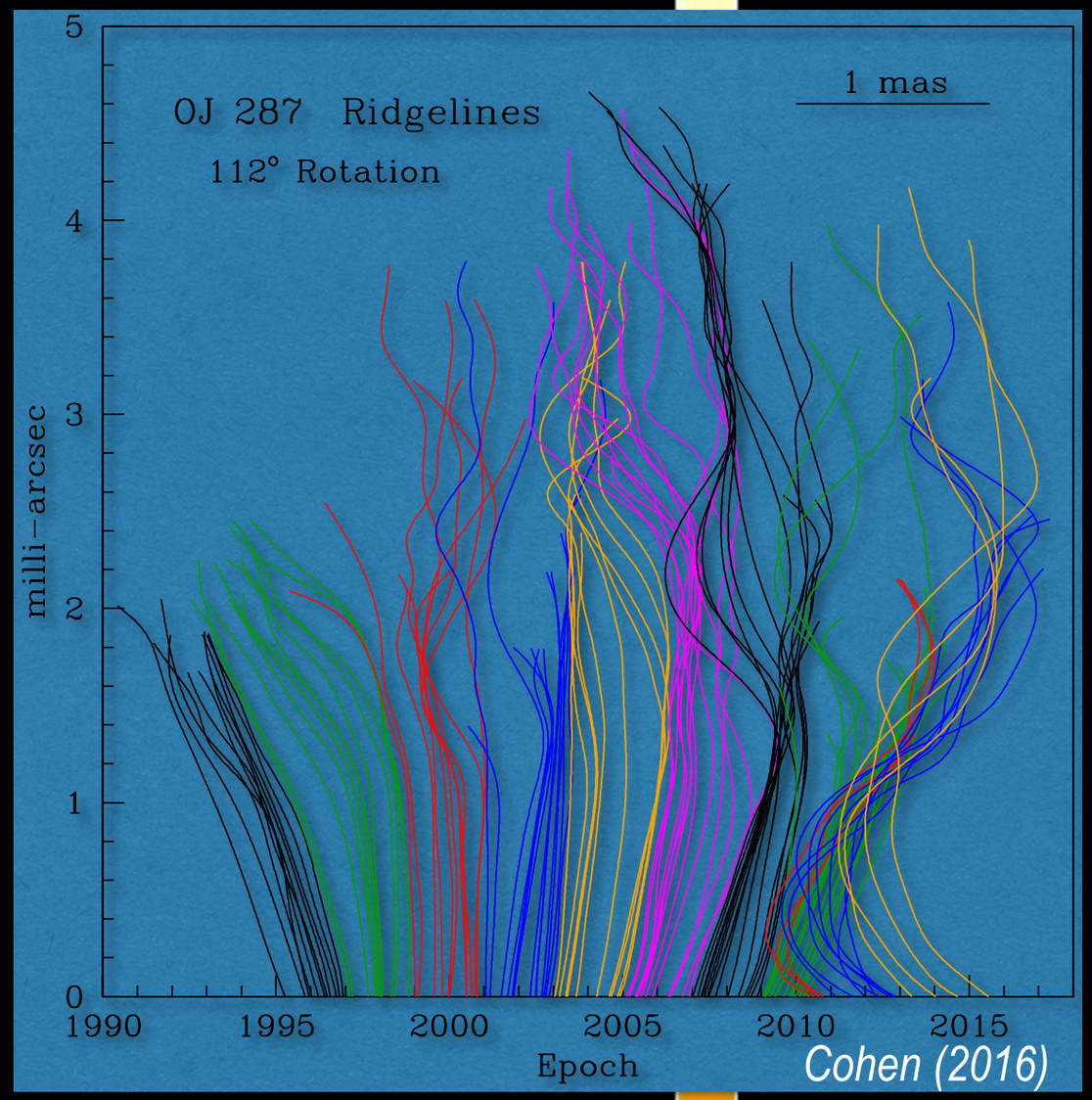
Natural
FWHM 140 μas



Relative Declination (mas)
0.4
0.2
0.0
-0.2

0.2 0.0 -0.2 -0.4 -0.6 -0.8
Relative Right Ascension (mas)

MOJAVE movie

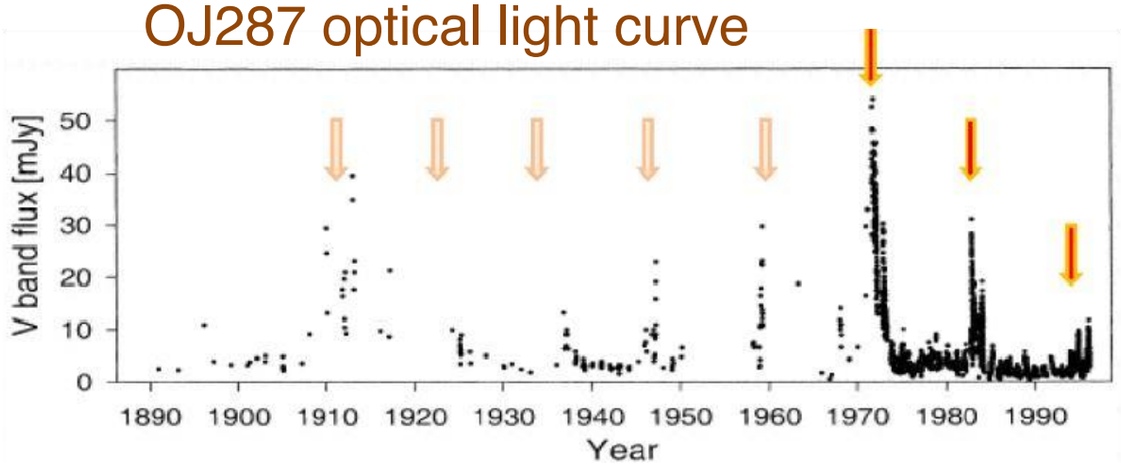


Observations of OJ287 at K-band

Optical double-peaks of OJ287 every ~12 years have been interpreted as the orbital period of a binary SMBH (Lehto & Valtonen 1996).

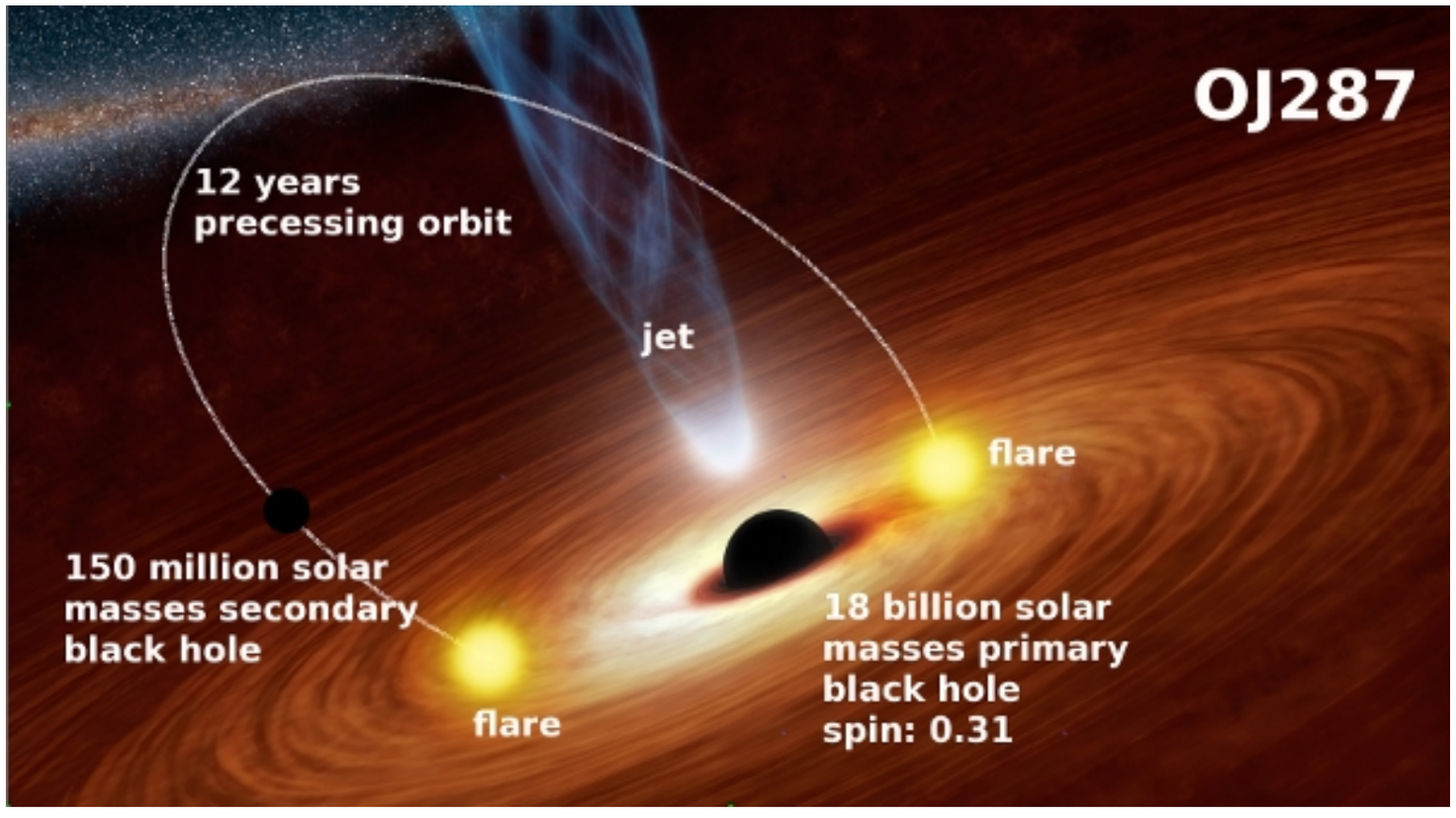
Optical thermal flares produced when the secondary SMBH impacts the disk around the primary SMBH.

OJ287 optical light curve

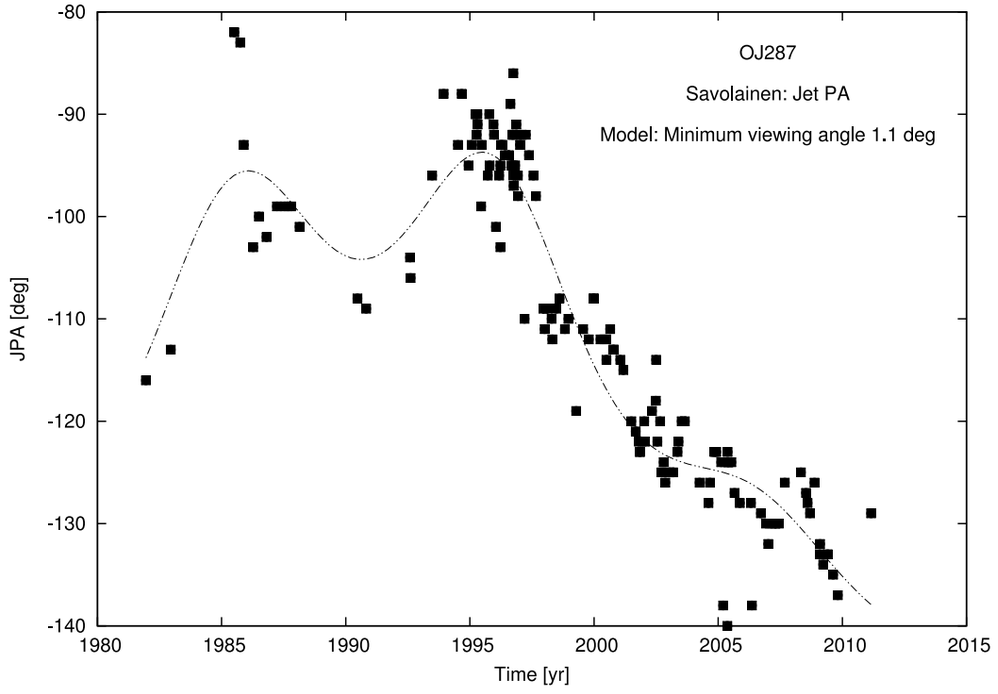


Orbital modeling (Valtonen et al. 2011, 2016) requires a compact binary with:

- Primary SMBH of $(1.83\pm0.01)\times10^{10}\ M_\odot$
- Secondary SMBH of $(1.5\pm0.1)\times10^{8}\ M_\odot$
- Eccentric orbit ($\varepsilon=0.700\pm0.001$) with a semi-major axis of 0.056 pc (~13 μas).
- Orbital shrinkage due to gravitational wave emission (at 2% accuracy level).



Fitting of jet position angle

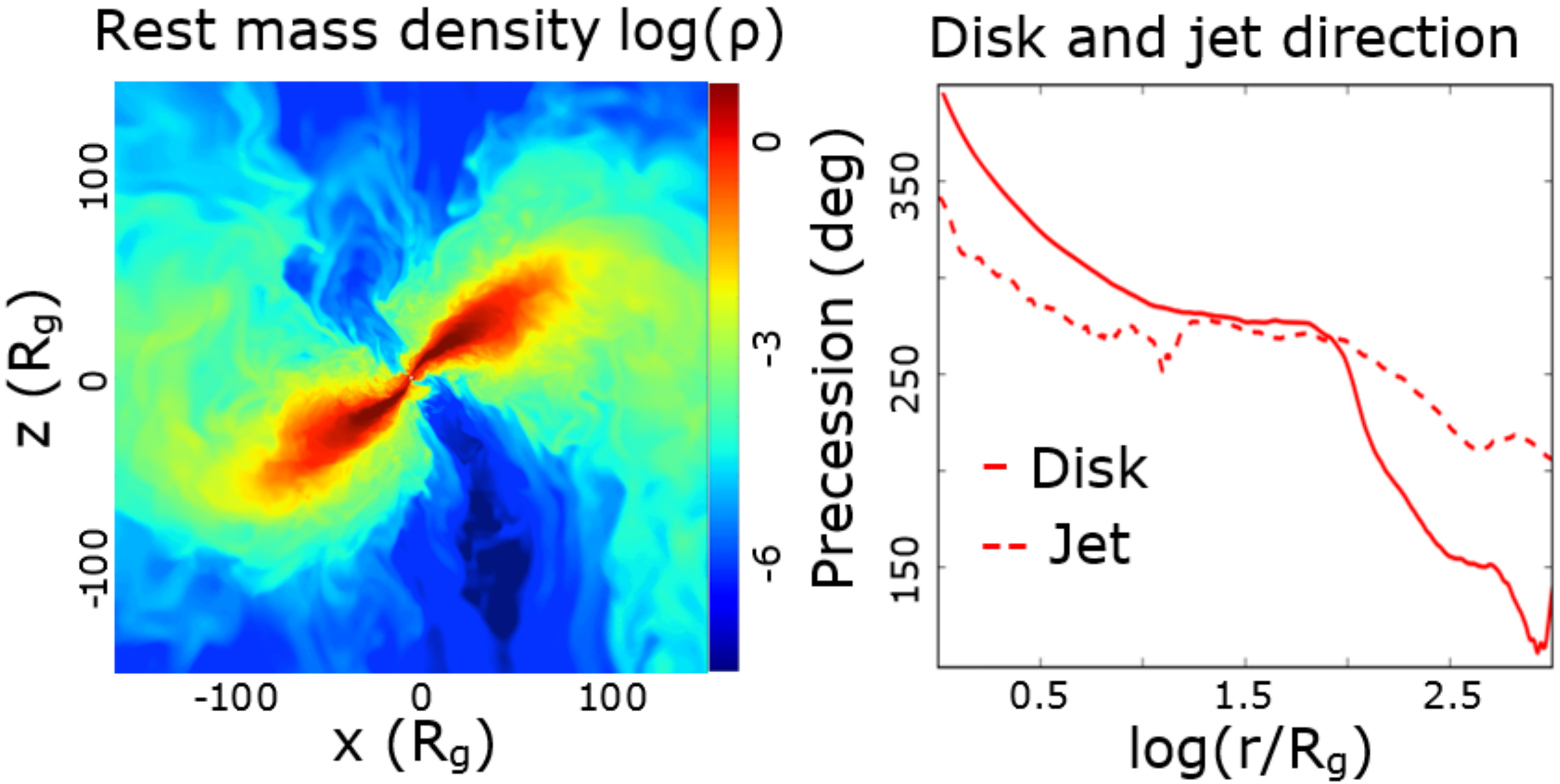


Observations of OJ287 at K-band

Alternatively, the innermost jet structure may result from the precession of a tilted accretion disk.

RMHD simulations of a thin accretion disk tilted by 60 deg. relative to the BH spin axis.

The disk and the jets precess at different rates, leading to quasi-periodic disk-jet interactions that could potentially account for the periodicity seen in OJ287 light curves.



Liska+ (in prep.)

SUMMARY

- 14 RadioAstron observations carried out within our polarization KSP during AO-1, AO-2, AO-3, and AO-4. Continued observations throughout AO-5.
- **BL Lac imaged at** L and K-bands. Ground-space fringes detected up to 8 D_E (7 D_E at L-band), achieving a maximum **angular resolution of ~20 μas**.
    - Evidence for emission upstream the core, and a pattern of three recollimation shocks (40, 100, 250 μas) that includes the core.
    - The ***intrinsic de-boosted*** **brightness temperature of the core exceeds 3×10^{12} K,** or ~6 times larger than the inverse Compton limit.
        - The core area shows a point symmetric structure in RM and EVPAs, suggesting it is **threaded by a helical magnetic field**.
- **OJ287 imaged with an angular resolution of ~10 μas** (15.2 D_E), suggesting a helical jet seen at small viewing angle, compatible with the supermassive binary black hole model.
- Confirmed polarization capabilities of RadioAstron for observations at 18 cm (Lobanov et al. 2015) and 1.3 cm (Gómez et al. 2016).

RadioAstron allows polarization imaging with angular resolutions of ~10 μas